GYROSCOPES

What they are, how they work, and how they affect our lives.

My Simple Science Series

An introduction to science with little or no math.

Thomas P. Ellliott

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Preface

You are now going to learn about what gyroscopes are, how they work, and where they are typically used. And, you won't need to be an expert on such things as trigonometry, vectors and angular velocity to do so. Our goal is to establish a practical understanding in the basics of gyroscopes, without needing a degree in engineering.

Introduction

Gyroscopes are amazing devices. Gyroscopes affect us every day without our being aware of it. You may have seen or perhaps even had a toy gyroscope. But gyroscopes are more than just a curious child's toy. They affect many things in our lives every day. Gyroscopes and their effects are present in ships, submarines, aircraft, missiles, and satellites. Even cell phones, cameras, and bicycles use gyroscopes and their unusual characteristics.

Have you learned to ride a bicycle, or watched someone else trying to learn? In the beginning it was a pretty unstable experience. During the first few attempts, you likely moved the handle bars back and forth to stay upright. If no one was there to catch you, there's a good chance that you and the bike wound up laying on the ground. It seemed that learning to balance on a bicycle would be an impossible task.

But after several tries, you found that you had traveled quite a distance. When you turned to look for your trainer, you found that you had left them far behind. Only then did you realize that you had been riding on your own. At some point your trainer sensed that you had figured out how to balance and they just let you go.

So why did it seem to be an impossible goal at first, and now you find it so easy to stay upright on a two wheeler? The answer is because of the bicycle wheels. Let's take a look at what a gyroscope is and how it works.

What is a mechanical gyroscope

A gyroscope is just a rotor or disc that is spinning on an axis. It has an axle along the axis that supports the rotor and provides a means to attach it to a frame or supporting ring. The axle has anti-friction bearings so it can spin easily at high speeds. A frame is not always necessary; a child's spinning top and a Frisbee are gyroscopes.

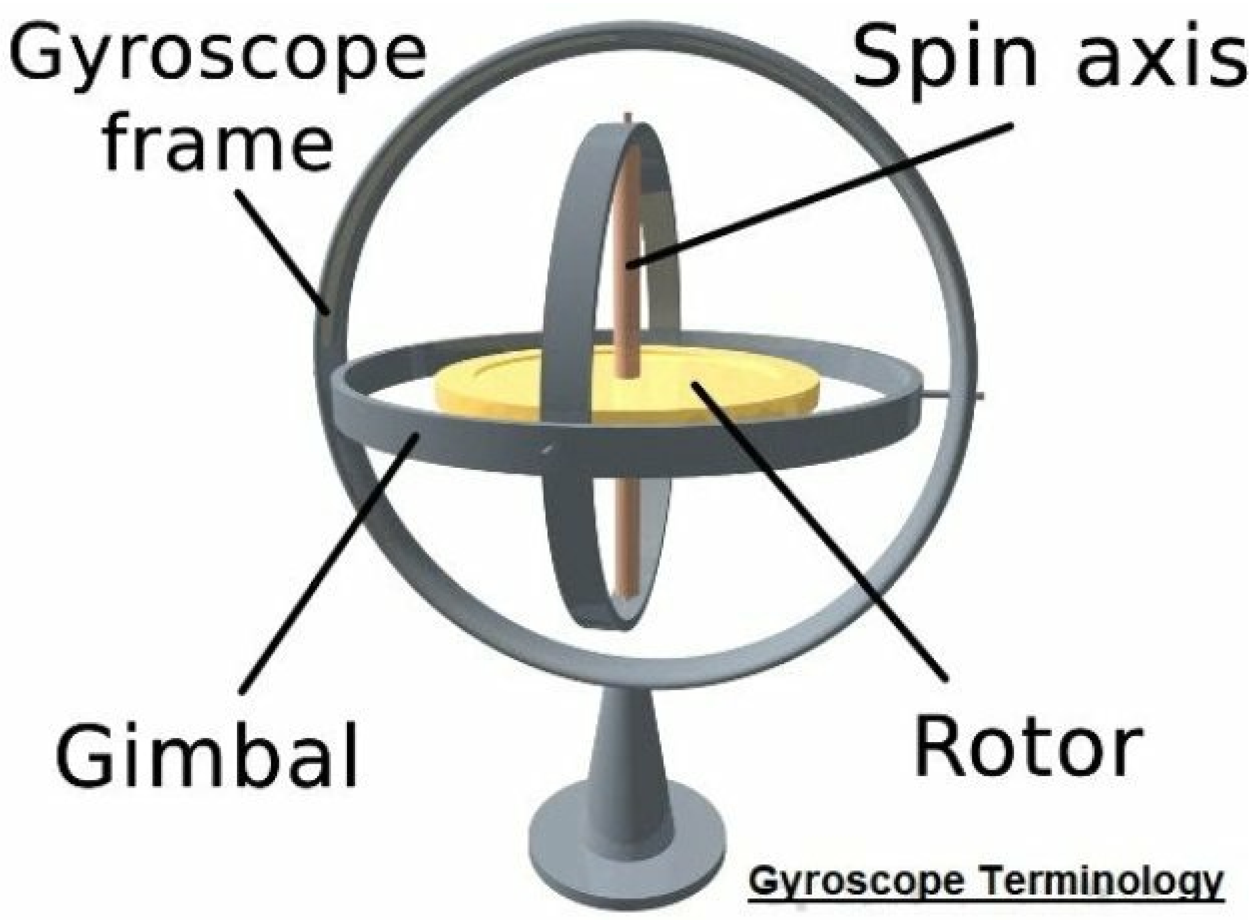
Yet most gyroscopes do have a frame to control the gyroscope, or to sense its effects. The frame is often mounted inside of one or two other frames called gimbals. This allows the gyro to move freely in relation to the plane, vehicle, or vessel where it is used.

The rotor may only be a flat disc. But rotors are usually designed to be thicker at the outer edge. This concentrates the mass at the perimeter. That's where the gyroscopic effects are the greatest.

We also need some way to make the rotor spin. On a toy gyroscope, we can pull a string wrapped around the axle to get it spinning. This will usually keep it spinning for several minutes. That is enough time to demonstrate the

gyroscopic effects. Those are the effects that first made it difficult, but later made it easy to ride the bicycle.

Sometimes it is necessary to keep the gyroscope spinning continuously. In these situations, an electric or air driven motor will do the work. Electric motors maintain a more constant speed. And, electric motors are not subject to dust and dirt as may be introduced in the air driven type. So what are these gyroscopic effects?



Gyroscopic effects

You can move a spinning gyroscope left to right, up or down, or forward and backwards. This is the same as you can move any other object. But, when you try to change the angle of the axis, or the plane of rotation of the rotor, you will feel resistance. This is when the unique characteristics of the gyroscope show up.

Rigidity in space

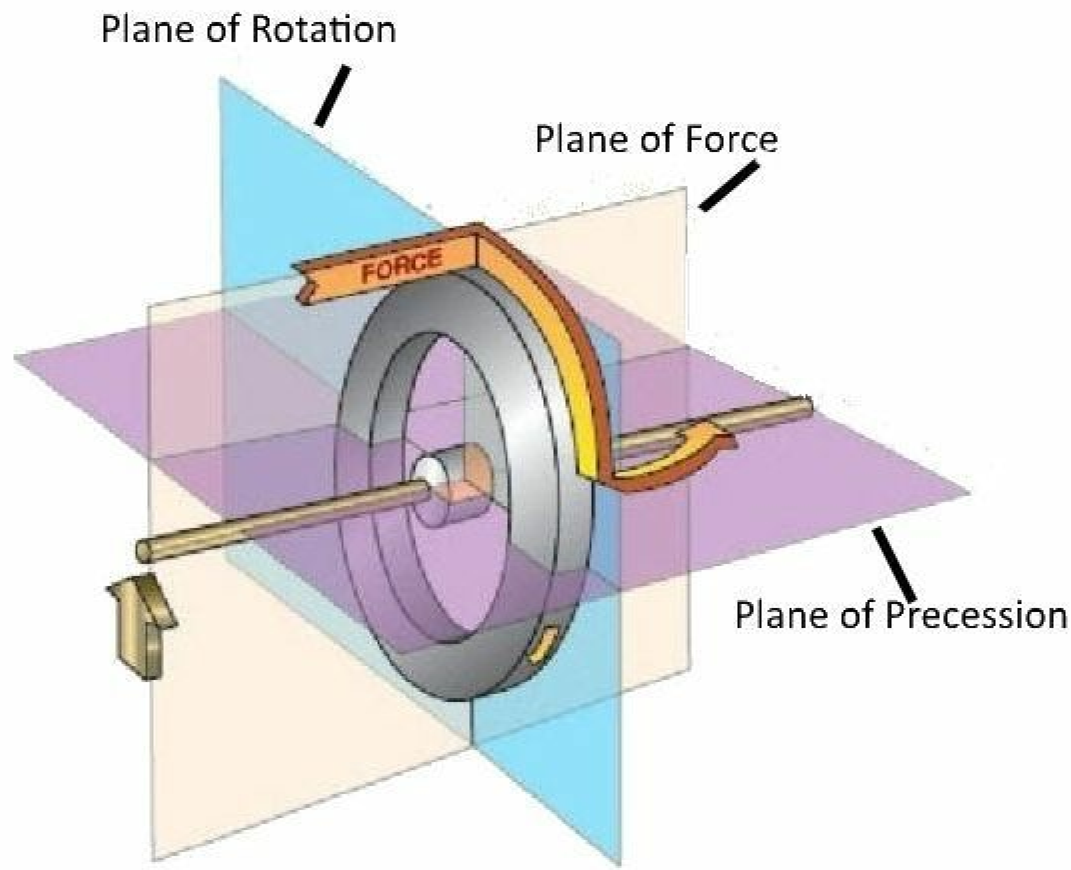
Rigidity in space means that a spinning gyroscope will maintain its orientation in space. It does so because of rotational inertia. Seventeenth century scientist and mathematician Sir Isaac Newton defined inertia in his First Law of Motion,

"An object at rest will remain at rest, and a moving object will remain in motion at a constant velocity, unless acted upon by an outside force".

Gyroscopic Rigidity in Space

Gyroscopic Precession

Gyroscopic Precession is another interesting characteristic of gyroscopes. Precession appears when you apply a force to change the angle of the axis of a spinning gyroscope. That force shows up 90 degrees later, in the direction of rotation of the rotor.



Gyroscopic Precession

Gyroscopic effects and the bicycle

Now let’s see what these gyroscopic effects have to do with operating our bicycle. When the wheel is turning, the rigidity in space tendency has a stabilizing effect. That’s what makes it easy to balance and stay upright.

When the bike is not moving, there is no gyroscopic effect to keep the bike upright. Balancing a stationary bicycle is much like trying to balance on a tight rope; most of us can’t do it. So you’ll have to put one or both feet on the ground.

Several motorcycle manufacturers have incorporated a gyroscope into some of their designs. The rider doesn’t have to put a foot on the ground when they come to a stop. The motorcycle remains upright while the gyroscope is spinning.

But, gyroscopic precession can work for us, or against us. When you try

to turn the bike by turning the front wheel to the left, you are applying a force that wants to move the back of the wheel to the right. Because of precession, the resulting force makes the top of the wheel tip to the right. That’s the opposite direction from the desired turn, and the bike tips over to the right.

Instead of turning the front wheel to the left, you can just lean gently to the left. When you tilt the top of the wheel to the left, precession causes the wheel to also turn to the left.

When you want to go straight again, you lean a bit to the right until you are going straight. It doesn’t take long to figure out how much leaning is necessary to turn. Once you get the feel for it, riding a bike is easy. You don’t need to think about it while you’re doing it. You subconsciously learn how to use the gyroscopic effects to your advantage.

Demonstrating gyroscopic effects

You can demonstrate gyroscopic rigidity in space by placing the gyroscope with the axis in the vertical position on a table. You can even balance it on a string. The gyroscope will remain upright as long as it is spinning fast.

If you support one end of a gyroscope's axle in the horizontal position, you can see the effect of gyroscopic precession. You can place the end of the axle on a stand or even suspend it with a string.

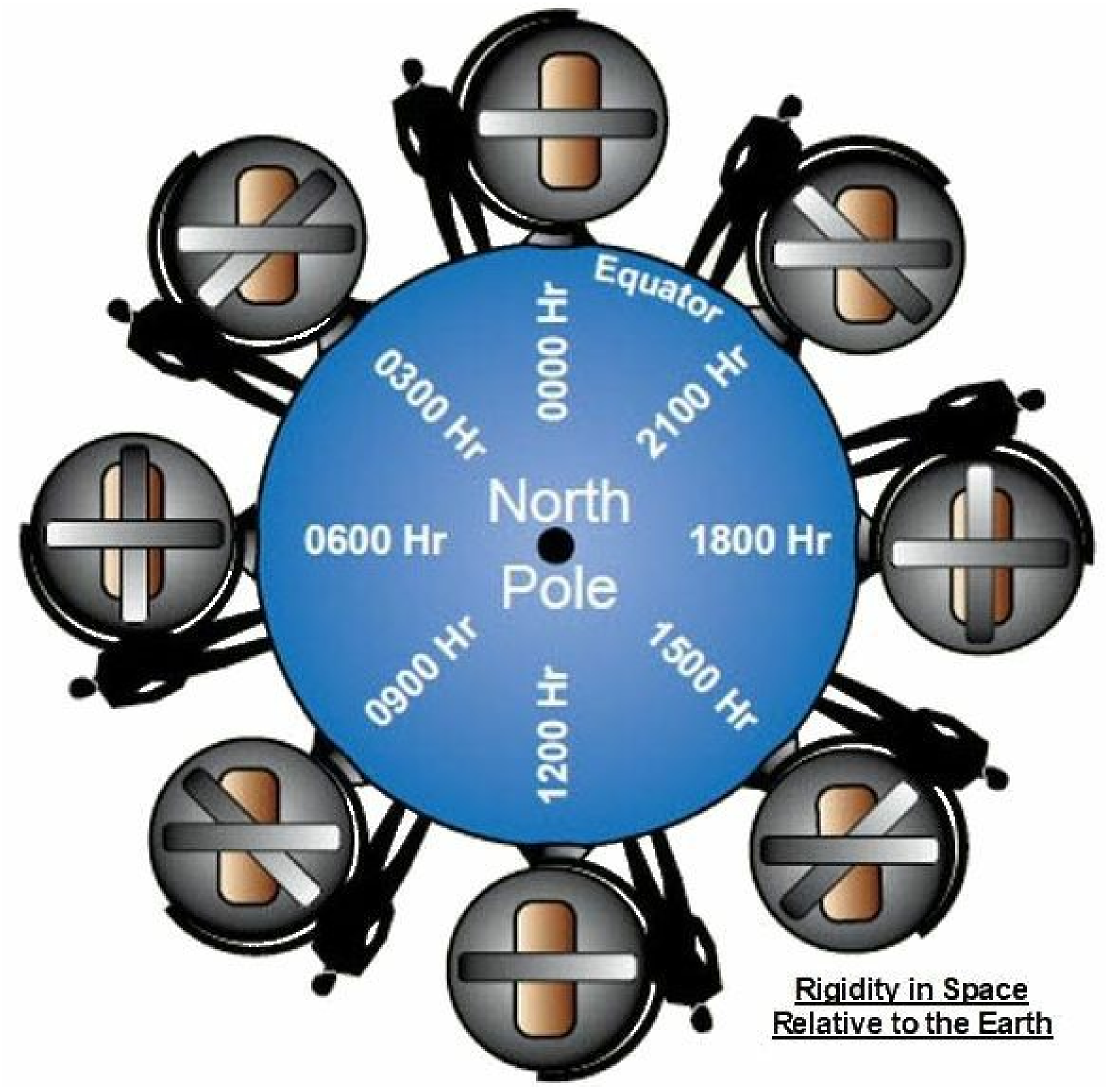
Gravity wants to pull the free end down, but it doesn’t fall. Gravity applies a force to tilt the rotor down. But, precession applies that force 90 degrees in the direction of rotation. This results in a horizontal movement around the point of suspension. But it doesn’t fall down.

Demonstrating Gyroscopic Effects

Practical applications for gyroscopes

Gyroscopes have been around for a few thousand years. But they were primarily in the form of children's toys such as spinning tops. Between the 16th and 18th centuries, Galileo and Sir Isaac Newton used spinning tops to study the effects of motion and related physics.

French scientist Jean Bernard Léon Foucault produced the first model of a gyrocompass in the 1850's. He demonstrated the gyroscope's rigidity in space in 1852. He showed this property in relation to the rotation of the earth. And, he is also credited with naming the gyroscope.



Practical applications of gyroscopes began to progress rapidly during the early 1900's. Among the early applications of gyroscopes were:

The Gyrocompass

The gyrocompass is a stable navigation device that replaces or supplements the magnetic compass. A magnetic compass points to magnetic north but it is subject to oscillations, especially in turbulent air or rough seas. The gyrocompass minimizes or eliminates those oscillations.

Unlike the magnetic compass, the gyrocompass is not affected by the metal in vessels or large ore deposits in the earth. And, when oriented to point to true north, it can simplify long range navigation. When coupled to a magnetic compass, a Gyroscopic Direction Indicator, or Directional Gyro

(DG), provides a stable reference to magnetic direction.

Gyrocompass

In 1885 Marinus Gerardus van den Bos of the Netherlands obtained the first patent for a gyrocompass. This was after the development of small electric motors that made continuous rotation of the gyroscope a possibility.

In 1906 Hermann Anschütz-Kaempfe developed the first practical gyrocompass. In 1911 Elmer A. Sperry produced a gyrocompass in the United States. The Sperry Corporation became a major manufacturer of navigation equipment.

Precision navigation systems

Gyroscopes provide a reliable reference for the development of long range navigation systems. These systems allow aircraft and sea-going vessels to navigate over great distances. And they can do it without reference to land based navigational aids.

Gyroscopic stabilization for ships

In the late 1800’s and early 1900’s, the installation of large gyroscopes in some ships provided a stable platform for vessels operating on rough seas. This could reduce roll from as much as 15 degrees to each side, down to as little as one degree of roll.

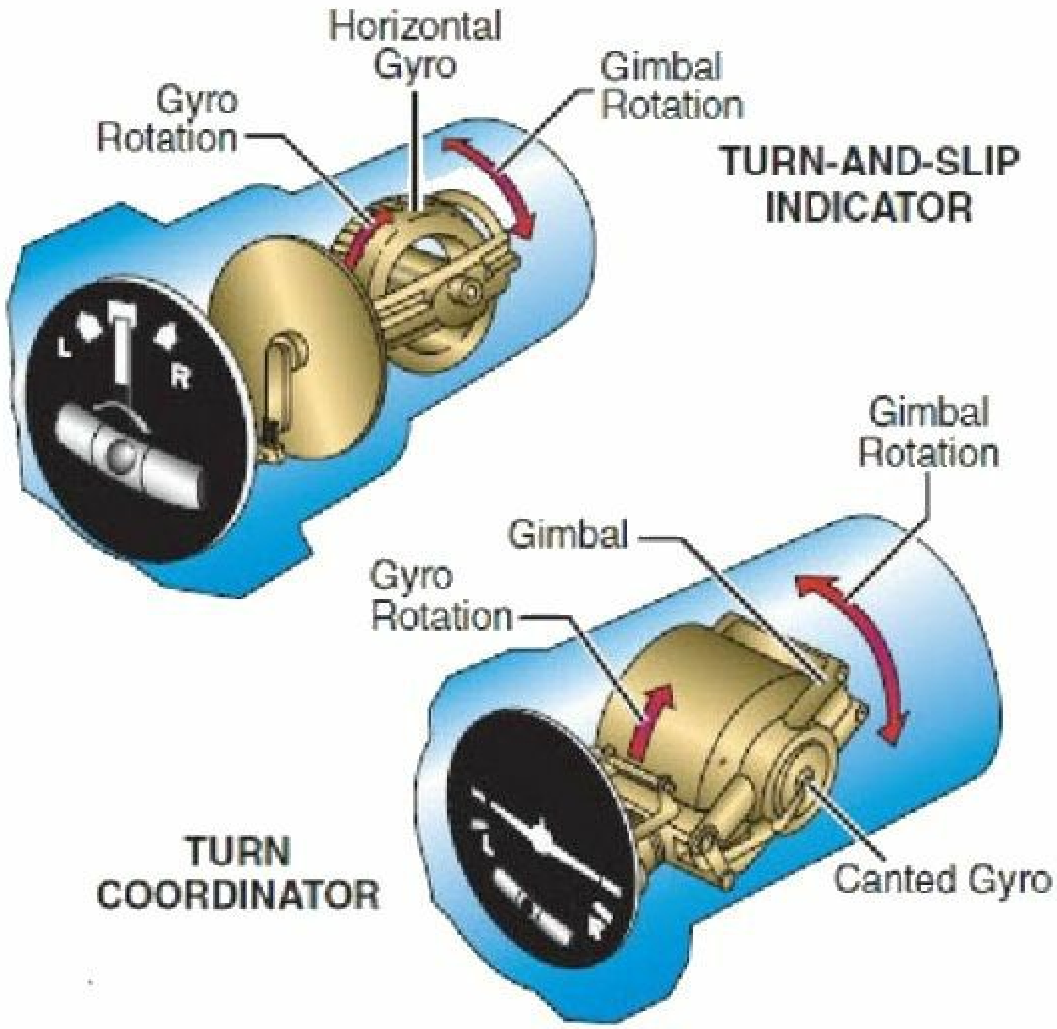
These installations were very expensive and heavy, and they took up a

lot of space. In 1925 the Japanese developed an underwater fin system that could stabilize ships. Soon after, the gyroscopic stabilization method became obsolete.

However, the 1990's brought a renewed interest in gyroscopic stabilization. This prompted the production of new gyroscopic stabilization systems. The fin system requires forward movement of the vessel to work. But the gyro system can eliminate rocking even when the boat is anchored. Many motorized yachts are now stabilized with gyroscopes.

The Gyroscopic Turn Indicator for aircraft

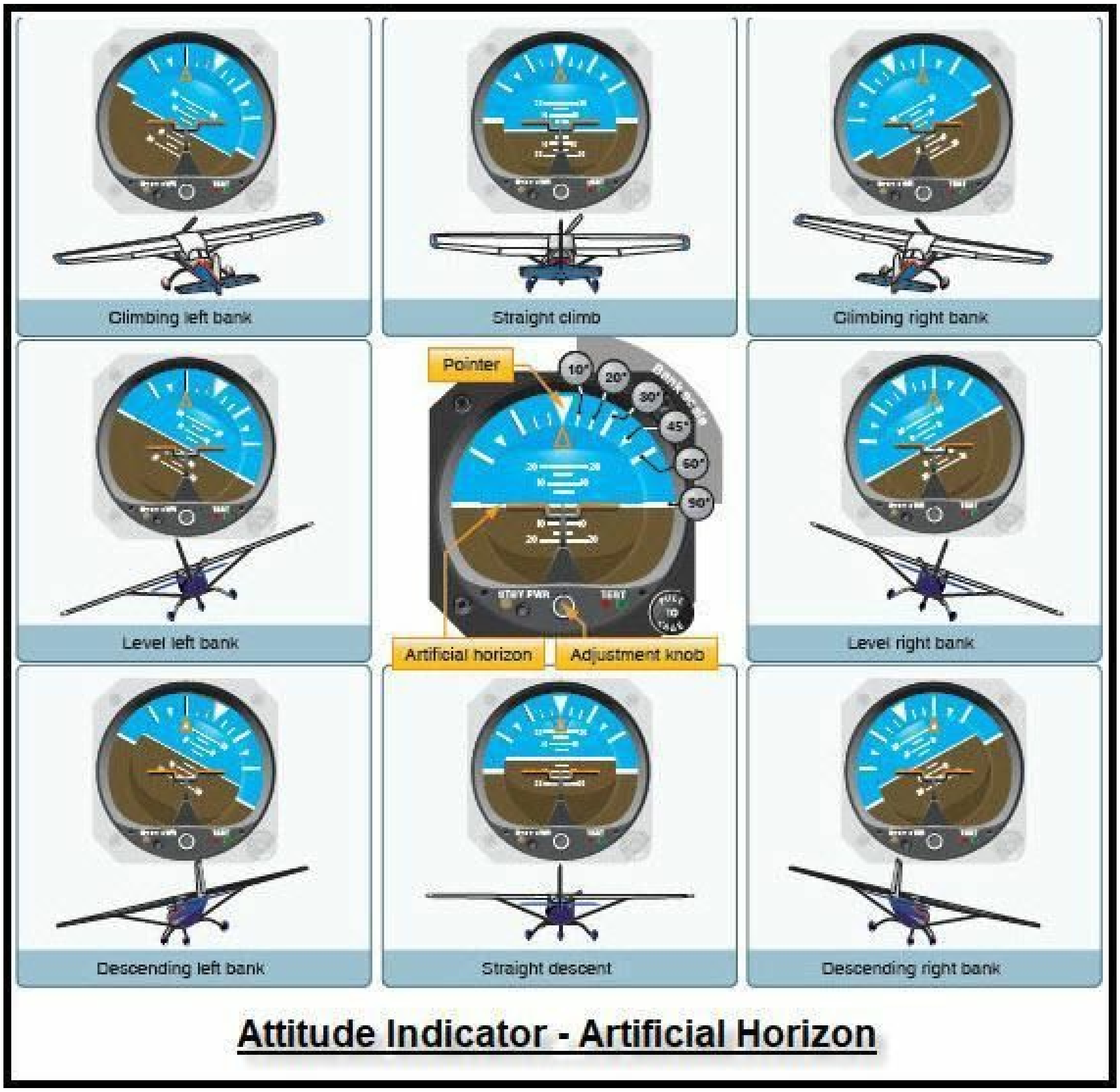
This was a major development in making instrument flying possible. It was further improved with the development of the Turn Coordinator. A Turn Coordinator anticipates turning as an airplane rolls towards the left or right.



Turn Indicator & Turn Coordinator

The Attitude Indicator:

The attitude indicator is also referred to as the Artificial Horizon. When flying in clouds pilots have no reference to the actual horizon outside of the aircraft. The Attitude Indicator allows pilots to have a visual simulation of the actual horizon. This was a significant advancement in making instrument flying easier and safer.



Attitude Indicator - Artificial Horizon

The Steadicam:

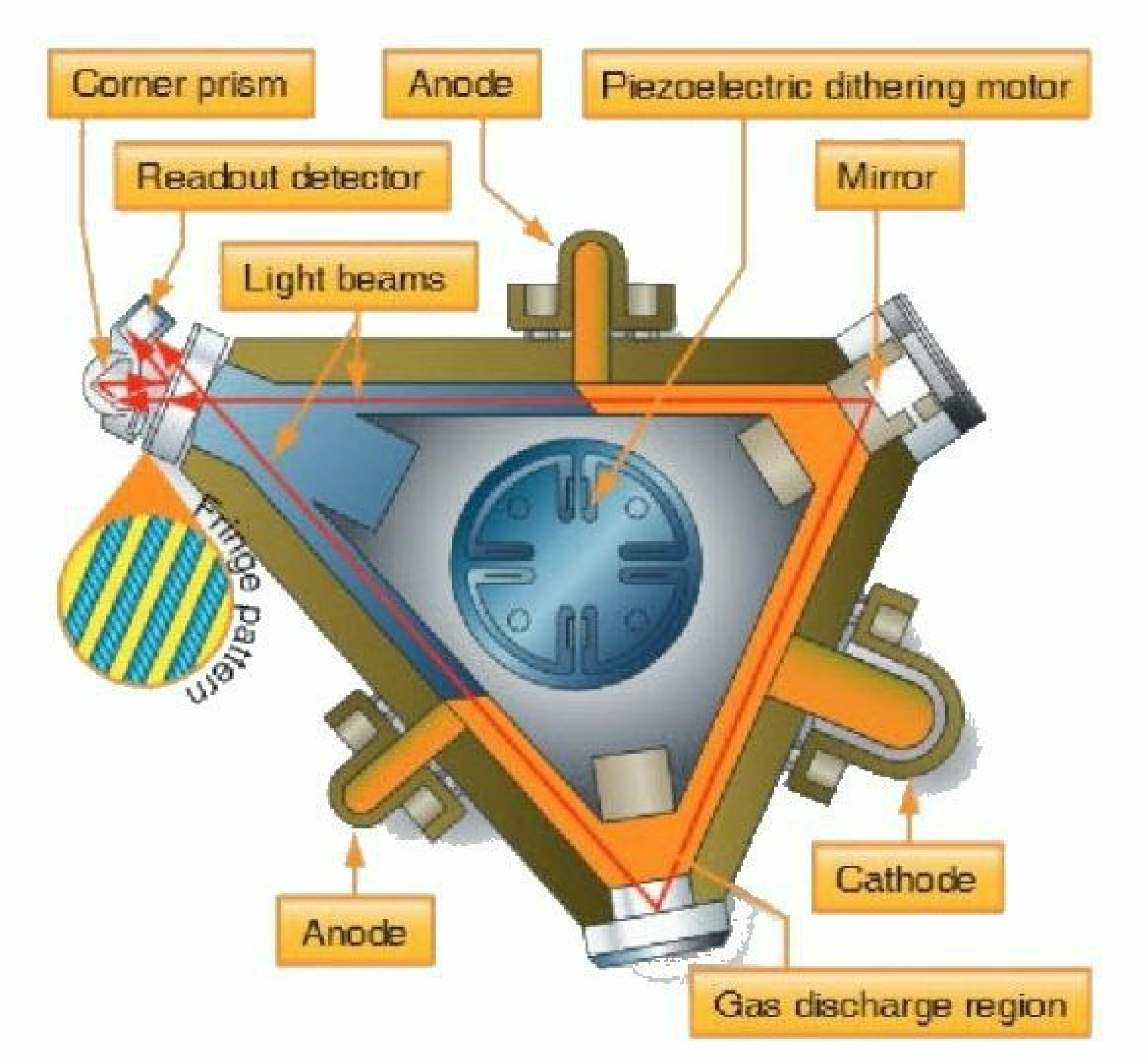
Garrett Brown invented the Steadicam in the 1970's. The Steadicam uses gyroscopes to provide a stable platform for hand-held cameras. Camera operators can wear the device like a vest so they can move about while filming. The stabilizing effect of the gyroscope allows for smooth motion pictures without shake or vibration. The Steadicam was used in 1976 for action scenes in such well known movies as: *Bound for Glory*, *Marathon Man*, and *Rocky*. It was also used in filming *The Shining* in 1980, *Return of the Jedi* in 1983, and *Runaway* in 1984. And, it continues to be used frequently by the film industry to stabilize filming of action scenes.

Other types of gyroscopes

The discussion so far has been about the properties of mechanical gyroscopes. But there are many other types of gyroscopes. These are rapidly replacing the mechanical variety in numerous applications. Solid state Gyro systems have been developed which have few or no moving parts. These systems need very little maintenance, they are light weight, and are very reliable. Several common types are Ring Gyroscopes, Fiber Optic Gyroscopes, and Micro-Electro-Mechanical Systems (MEMS).

Ring Laser Gyros (RLG)

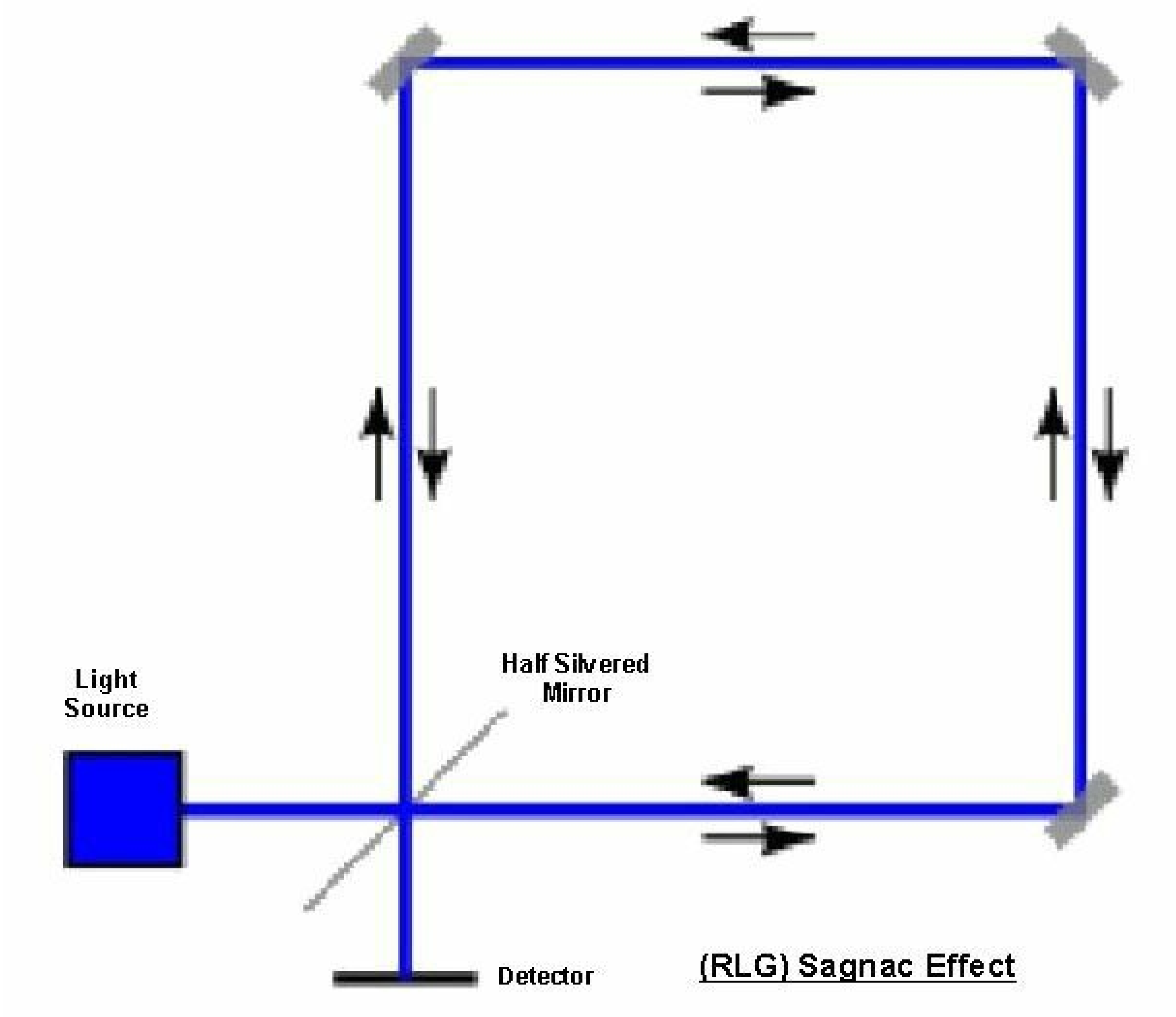
In Ring Laser Gyros, a laser light beam splits into two beams. And then the two beams travel in opposite directions in a circle or ring. Although it's called a ring, the actual path is more like a triangle or rectangle. This is accomplished with mirrors.



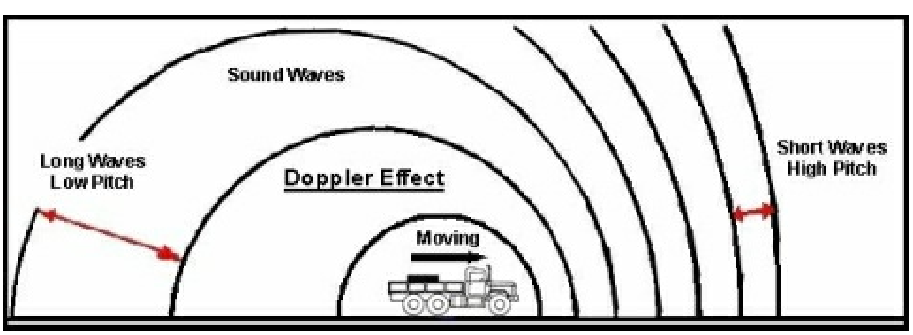
Ring Laser Gyroscope

If the base is stationary, the two beams complete their circuit in the same length of time and travel the same distance. But, if the base is rotating, the light beam that is traveling in the same direction that the base is turning will take longer to reach its target or sensor. This is because the sensor is moving away from the light source.

The light beam that is traveling in the opposite direction of the rotating base will reach its destination sooner. This is because the sensor is moving toward the source of light. French physicist Georges Sagnac was able to demonstrate this in 1913. It is now called the Sagnac effect.



You might think of the Sagnac effect as being somewhat like the Doppler Effect with sound waves. An approaching train or car has a high pitch sound, and after it passes it has a lower pitch sound.



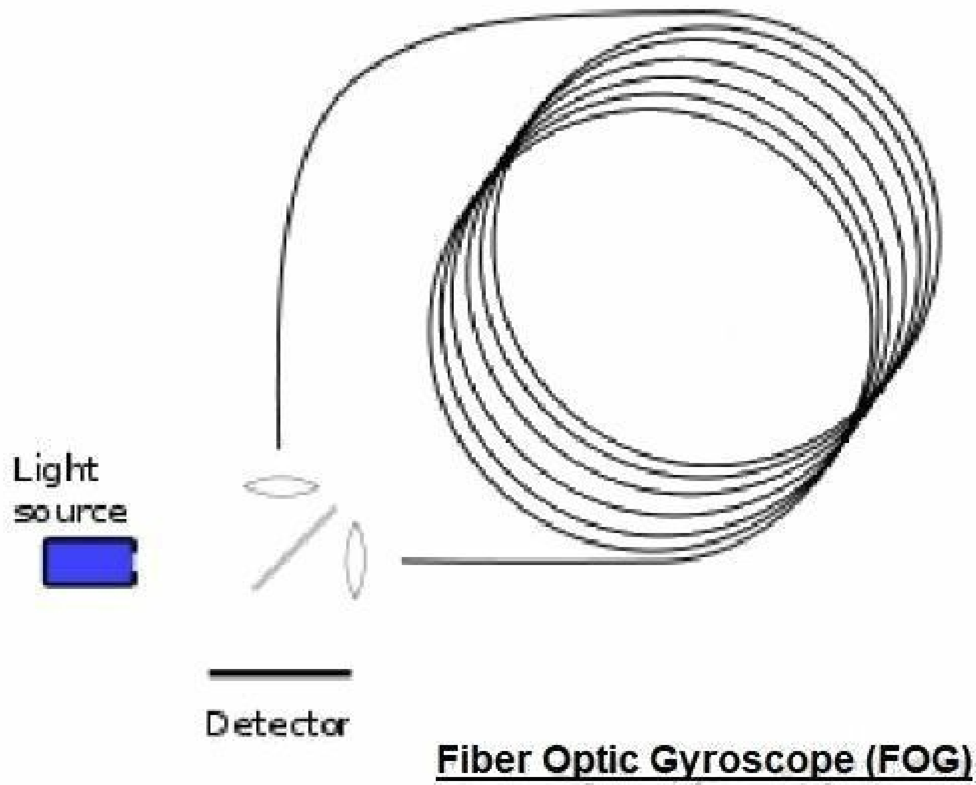
This is because when the source of the sound and the receiver are

approaching each other, the receiver gets each cycle of the sound wave sooner. This shows up as an apparent higher frequency. When the distance between the source of the sound and the receiver is increasing, it takes longer for the waves to reach the receiver. The result is an apparent lower frequency.

Sensitive electronics in Ring Laser Gyroscopes measure these differences in the apparent frequency of the two light beams. This information is then converted into direction and velocity. Several Ring Laser Gyros mounted with different orientation can detect motion and velocity in any direction.

Fiber Optic Gyroscopes (FOG)

Fiber Optic Gyroscopes also use the Sagnac effect to detect motion. Instead of using mirrors as with Ring Laser Gyros, Fiber Optic Gyroscopes pass a split light beam through coils of optical fiber. The optical fiber is typically slightly thicker than a human hair. It is wound in coils that can be several kilometers in length. Increasing the number of loops in the coil increases the Sagnac effect. Fiber Optic Gyros have excellent resolution, are light weight, and are very reliable.



Micro-Electro-Mechanical Systems (MEMS)

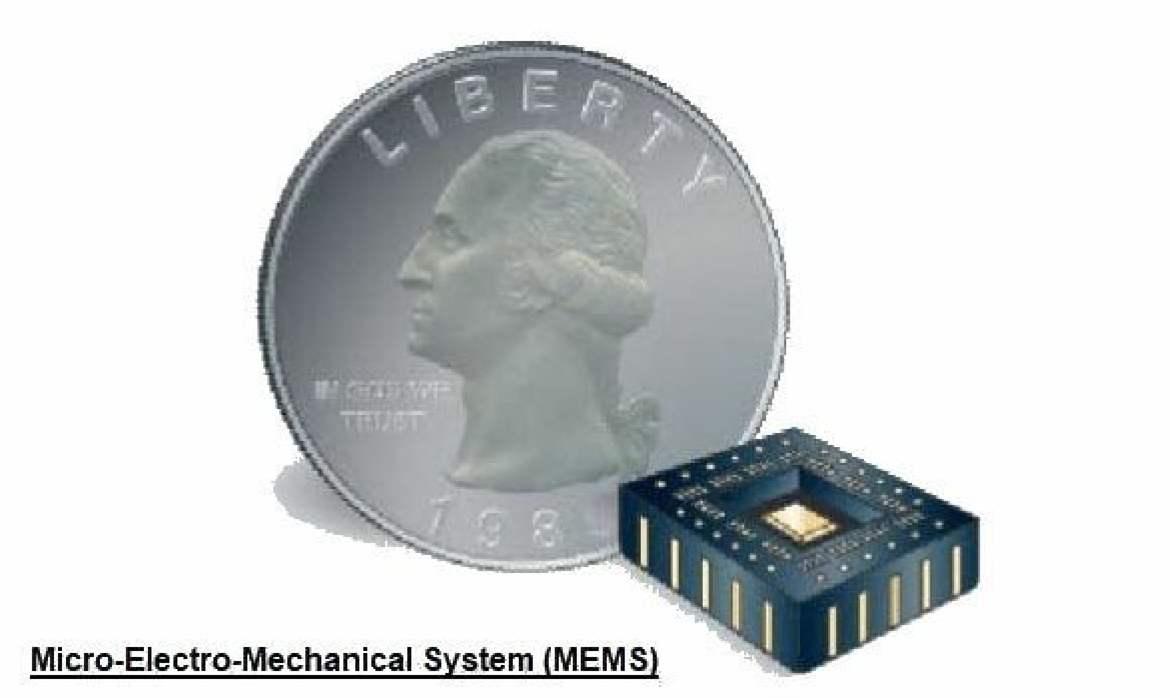
MEMS gyroscopes are the most widely used of several types of vibrating gyros. Vibrating gyroscopes work on the principle of rigidity in space. A vibrating element will vibrate in the same plane in space, unless acted upon by an outside force.

This is much like the operation of the mechanical gyroscope. The vibrating element tries to resist any change in its plane of vibration. The force and direction is measured at the base of the vibrating element as a change in electrical resistance, voltage, or capacitance.

There are many different materials that can be used for the vibrating elements. Metal, diamonds, quartz, ceramics, and silicone are just a few. The length of each vibrating element may be very small. They may be anywhere from one tenth of a millimeter (0.1mm) to as little as one thousandth of a millimeter (0.001mm).

Many vibrating elements can be mounted in various orientations on a single chip. The entire MEMS gyroscope is usually smaller than the diameter

of most coins and just several coins in thickness.



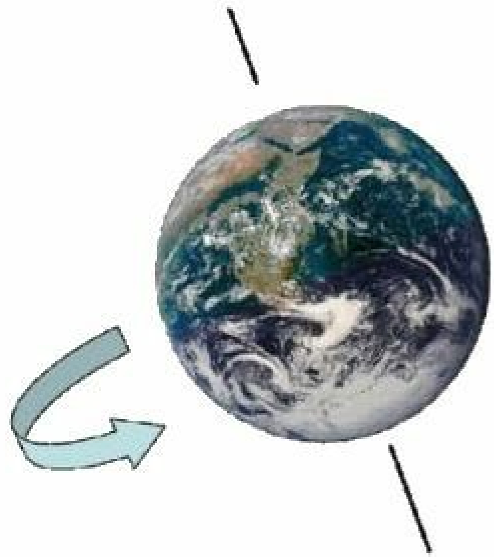
Micro-Electro-Mechanical System (MEMS)

Almost everyone has a MEMS gyroscope. They exist in smart phones and GPS devices. They are quite reliable and sense both direction and rate of movement. A slight movement of your cell phone will awaken its display screen. And, you might program your phone to turn on its camera or flashlight function with two quick shakes or a single rapid rotation.

Conclusion

So now you know how gyroscopes work and that they are all around us, affecting our lives every day. As a matter of fact, we are riding on a gyroscope. That’s right; the Earth itself is a gigantic gyroscope.

The Earth maintains its orientation in space by rotating as a gyroscope. The relationship of the angle of the earth’s axis to the sun changes as the earth revolves around the sun. This is the reason we have different seasons. Some scientists believe that may even be why life had the chance to begin on our planet.



Earth - A gigantic gyroscope

If you would like to learn more about the science behind gyroscopes, there are many good text books available. These can help you delve deeper into the physics of this subject.

But with the knowledge you have gained here, you can be sure that you already know more about gyroscopes than most people on the planet.